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6581 SOUND INTERFACE DEVICE (SID)

CONCEPT

The 6581 Sound Interface Device (SID) is a single-chip, 3-voice electronic music synthesizer/sound effects generator compatible with the 65XX and similar microprocessor families. SID provides wide-range, high-resolution control of pitch (frequency), tone color (harmonic content) and dynamics (volume). Specialized control circuitry minimizes software overhead, facilitating use in arcade/home video games and low-cost musical instruments.

FEATURES

- **3 TONE OSCILLATORS**
  - Range: 0-4 kHz
- **4 WAVEFORMS PER OSCILLATOR**
  - Triangle, Sawtooth,
  - Variable Pulse, Noise
- **3 AMPLITUDE MODULATORS**
  - Range: 48 dB
- **3 ENVELOPE GENERATORS**
  - Exponential response
  - Attack Rate: 2mS-8S
  - Decay Rate: 6mS-24S
  - Sustain Level: 0-peak volume
  - Release Rate: 6mS-24S
- **OSCILLATOR SYNCHRONIZATION**
- **RING MODULATION**
- **PROGRAMMABLE FILTER**
  - Cutoff range: 30 Hz-12 kHz
  - 12 dB/octave Rolloff
  - Low pass, Band pass,
  - High pass, Notch outputs
  - Variable Resonance
- **MASTER VOLUME CONTROL**
- **2 A/D POT INTERFACES**
- **RANDOM NUMBER/MODULATION GENERATOR**
- **EXTERNAL AUDIO INPUT**

6581 PIN CONFIGURATION

Pin	#		#	Pin
CAP1A	1		28	Vdd
CAP1B	2		27	AUDIO OUT
CAP2A	3		26	EXT IN
CAP2B	4	6581	25	Vcc
RES	5	SID	24	POT X
02	6		23	POT Y
R/W	7		22	D7
CS	8		21	D6
A0	9		20	D5
A1	10		19	D4
A2	11		18	D3
A3	12		17	D2
A4	13		16	D1
GND	14		15	D0

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## DESCRIPTION

The 6581 consists of three synthesizer "voices" which can be used independently or in conjunction with each other (or external audio sources) to create complex sounds. Each voice consists of a Tone Oscillator/Waveform Generator, an Envelope Generator and an Amplitude Modulator. The Tone Oscillator controls the pitch of the voice over a wide range. The Oscillator produces four waveforms at the selected frequency, with the unique harmonic content of each waveform providing simple control of tone color. The volume dynamics of the oscillator are controlled by the Amplitude Modulator under the direction of the Envelope Generator. When triggered, the Envelope Generator creates an amplitude envelope with programmable rates of increasing and decreasing volume. In addition to the three voices, a programmable Filter is provided for generating complex, dynamic tone colors via subtractive synthesis.

SID allows the microprocessor to read the changing output of the third Oscillator and third Envelope Generator. These outputs can be used as a source of modulation information for creating vibrato, frequency/filter sweeps and similar effects. The third oscillator can also act as a random number generator for games. Two A/D converters are provided for interfacing SID with potentiometers. These can be used for "paddles" in a game environment or as front panel controls in a music synthesizer. SID can process external audio signals, allowing multiple SID chips to be daisy-chained or mixed in complex polyphonic systems.
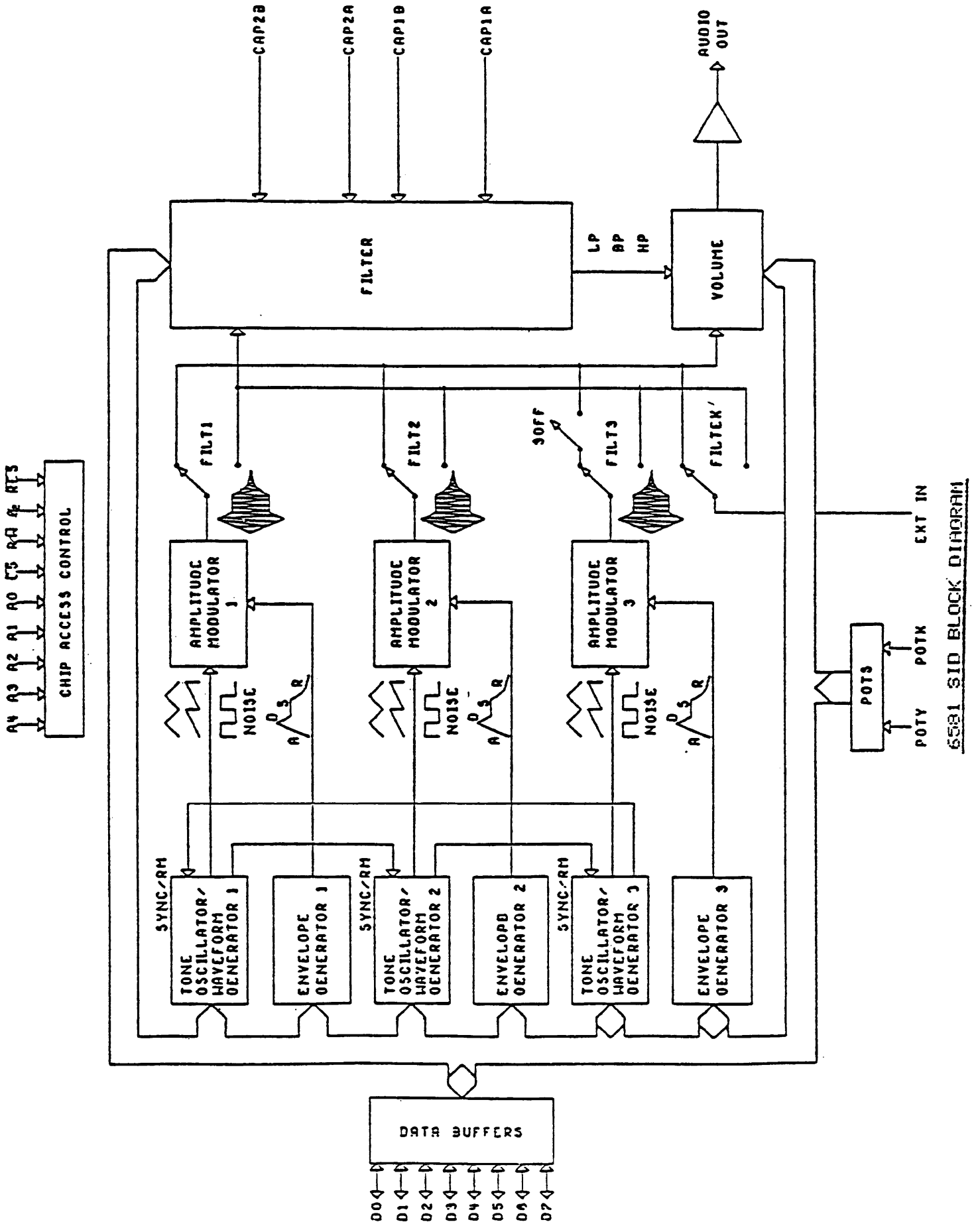
6581 SID BLOCK DIAGRAM

SID CONTROL REGISTERS

There are 29 eight-bit registers in SID which control the generation of sound. These registers are either WRITE-only or READ-only and are listed below in Table 1.

	ADDRESS					REG #	DATA								REG	REG
	A4	A3	A2	A1	A0	(HEX)	D7	D6	D5	D4	D3	D2	D1	D0	NAME	TYPE
															VOICE 1	
0	0	0	0	0	0	00	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0	FREQ LO	WRITE-only
1	0	0	0	0	1	01	F_{15}	F_{14}	F_{13}	F_{12}	F_{11}	F_{10}	F_9	F_8	FREQ HI	WRITE-only
2	0	0	0	1	0	02	PW_7	PW_6	PW_5	PW_4	PW_3	PW_2	PW_1	PW_0	PW LO	WRITE-only
3	0	0	0	1	1	03	—	—	—	—	PW_{11}	PW_{10}	PW_9	PW_8	PW HI	WRITE-only
4	0	0	1	0	0	04	NOISE	⊓⊔	∧∧	∧	TEST	RING MOD	SYNC	GATE	CONTROL REG	WRITE-only
5	0	0	1	0	1	05	ATK_3	ATK_2	ATK_1	ATK_0	DCY_3	DCY_2	DCY_1	DCY_0	ATTACK/DECAY	WRITE-only
6	0	0	1	1	0	06	STN_3	STN_2	STN_1	STN_0	RLS_3	RLS_2	RLS_1	RLS_0	SUSTAIN/RELEASE	WRITE-only
															VOICE 2	
7	0	0	1	1	1	07	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0	FREQ LO	WRITE-only
8	0	1	0	0	0	08	F_{15}	F_{14}	F_{13}	F_{12}	F_{11}	F_{10}	F_9	F_8	FREQ HI	WRITE-only
9	0	1	0	0	1	09	PW_7	PW_6	PW_5	PW_4	PW_3	PW_2	PW_1	PW_0	PW LO	WRITE-only
10	0	1	0	1	0	0A	—	—	—	—	PW_{11}	PW_{10}	PW_9	PW_8	PW HI	WRITE-only
11	0	1	0	1	1	0B	NOISE	⊓⊔	∧∧	∧	TEST	RING MOD	SYNC	GATE	CONTROL REG	WRITE-only
12	0	1	1	0	0	0C	ATK_3	ATK_2	ATK_1	ATK_0	DCY_3	DCY_2	DCY_1	DCY_0	ATTACK/DECAY	WRITE-only
13	0	1	1	0	1	0D	STN_3	STN_2	STN_1	STN_0	RLS_3	RLS_2	RLS_1	RLS_0	SUSTAIN/RELEASE	WRITE-only
															VOICE 3	
14	0	1	1	1	0	0E	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0	FREQ LO	WRITE-only
15	0	1	1	1	1	0F	F_{15}	F_{14}	F_{13}	F_{12}	F_{11}	F_{10}	F_9	F_8	FREQ HI	WRITE-only
16	1	0	0	0	0	10	PW_7	PW_6	PW_5	PW_4	PW_3	PW_2	PW_1	PW_0	PW LO	WRITE-only
17	1	0	0	0	1	11	—	—	—	—	PW_{11}	PW_{10}	PW_9	PW_8	PW HI	WRITE-only
18	1	0	0	1	0	12	NOISE	⊓⊔	∧∧	∧	TEST	RING MOD	SYNC	GATE	CONTROL REG	WRITE-only
19	1	0	0	1	1	13	ATK_3	ATK_2	ATK_1	ATK_0	DCY_3	DCY_2	DCY_1	DCY_0	ATTACK/DECAY	WRITE-only
20	1	0	1	0	0	14	STN_3	STN_2	STN_1	STN_0	RLS_3	RLS_2	RLS_1	RLS_0	SUSTAIN/RELEASE	WRITE-only
															FILTER	
21	1	0	1	0	1	15	—	—	—	—	—	FC_2	FC_1	FC_0	FC LO	WRITE-only
22	1	0	1	1	0	16	FC_{10}	FC_9	FC_8	FC_7	FC_6	FC_5	FC_4	FC_3	FC HI	WRITE-only
23	1	0	1	1	1	17	RES_3	RES_2	RES_1	RES_0	$FILT_3$	$FILT_2$	$FILT_1$	$FILT$	RES/FILT	WRITE-only
24	1	1	0	0	0	18	3OFF	HP	BP	LP	VOL_3	VOL_2	VOL_1	VOL_0	MODE/VOL	WRITE-only
															MISC	
25	1	1	0	0	1	19	PX_7	PX_6	PX_5	PX_4	PX_3	PX_2	PX_1	PX_0	POTX	READ-only
26	1	1	0	1	0	1A	PY_7	PY_6	PY_5	PY_4	PY_3	PY_2	PY_1	PY_0	POTY	READ-only
27	1	1	0	1	1	1B	O_7	O_6	O_5	O_4	O_3	O_2	O_1	O_0	OSC3/RANDOM	READ-only
28	1	1	1	0	0	1C	E_7	E_6	E_5	E_4	E_3	E_2	E_1	E_0	ENV3	READ-only

TABLE 1 — SID REGISTER MAP

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SID REGISTER DESCRIPTION

VOICE 1

FREQ LO/FREQ HI (Registers 00,01) -

Together these registers form a 16-bit number which linearly controls the Frequency of Oscillator 1. The frequency is determined by the following equation:

$$Fout = (Fn * Fclk/16777216)\ Hz$$

Where Fn is the 16-bit number in the Frequency registers and Fclk is the system clock applied to the $\phi 2$ input (pin 6). For a standard 1.0 Mhz clock, the frequency is given by:

$$Fout = (Fn * 0.0596)\ Hz$$

A complete table of values for generating 8 octaves of the equally-tempered musical scale with concert A (440 Hz) tuning is provided in appendix A. It should be noted that the frequency resolution of SID is sufficient for any tuning scale and allows sweeping from note to note (portamento) with no discernable frequency steps.

PW LO/PW HI (Registers 02,03) -

Together these registers form a 12-bit number (bits 4-7 of PW HI are not used) which linearly controls the Pulse Width (duty cycle) of the Pulse waveform on Oscillator 1. The pulse width is determined by the following equation:

$$PWout = (PWn/40.95)\ \%$$

Where PWn is the 12-bit number in the Pulse Width registers.

The pulse width resolution allows the width to be smoothly swept with no discernable stepping. Note that the Pulse waveform on Oscillator 1 must be selected in order for the Pulse Width registers to have any audible effect. A value of 0 or 4095 ($FFF) in the Pulse Width registers will produce a constant DC output, while a value of 2048 ($800) will produce a square wave.

CONTROL REGISTER (Register 04) -

This register contains eight control bits which select various options on Oscillator 1.

GATE (Bit 0) - The GATE bit controls the Envelope Generator for Voice 1. When this bit is set to a one, the Envelope Generator is Gated (triggered) and the ATTACK/DECAY/SUSTAIN cycle is initiated. When the bit is reset to a zero, the RELEASE cycle begins. The Envelope Generator controls the amplitude of Oscillator 1 appearing at the audio output, therefore, the GATE bit must be set (along with suitable envelope parameters) for the selected output of Oscillator 1 to be audible. A detailed discussion of the Envelope Generator can be found in Appendix B.

SYNC (Bit 1) - The SYNC bit, when set to a one, Synchronizes the fundamental frequency of Oscillator 1 with the fundamental frequency of Oscillator 3, producing "Hard Sync" effects. Varying the frequency of Oscillator 1 with respect to Oscillator 3 produces a wide range of complex harmonic structures from Voice 1 at the frequency of Oscillator 3.' In order for sync to occur, Oscillator 3 must be set to some frequency other than zero but preferably lower than the frequency of Oscillator 1. No other parameters of Voice 3 have any effect on sync.

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RING MOD (Bit 2) - The RING MOD bit, when set to a one, replaces the
Triangle waveform output of Oscillator 1 with a "Ring Modulated"
combination of Oscillators 1 and 3. Varying the frequency of
Oscillator 1 with respect to Oscillator 3 produces a wide range
of non-harmonic overtone structures for creating bell or gong
sounds and for special effects. In order for ring modulation to
be audible, the Triangle waveform of Oscillator 1 must be selected
and Oscillator 3 must be set to some frequency other than zero.
No other parameters of Voice 3 have any effect on ring modulation.

TEST (Bit 3) - The TEST bit, when set to a one, resets and locks
Oscillator 1 at zero until the TEST bit is cleared. The Noise
waveform output of Oscillator 1 is also reset and the Pulse
waveform output is held at a DC level. Normally this bit
is used for testing purposes, however, it can be used to
synchronize Oscillator 1 to external events, allowing the
generation of highly complex waveforms under real-time software
control.

◿◿ (Bit 4) - When set to a one, the Triangle waveform output of
Oscillator 1 is selected. The Triangle waveform is low in
harmonics and has a mellow, flute-like quality.

◿◿ (Bit 5) - When set to a one, the Sawtooth waveform output of
Oscillator 1 is selected. The Sawtooth waveform is rich in
even and odd harmonics and has a bright, brassy quality.

⊓⊔ (Bit 6) - When set to a one, the Pulse waveform output of
Oscillator 1 is selected. The harmonic content of this waveform
can be adjusted by the Pulse Width registers, producing tone
qualities ranging from a bright, hollow square wave to a nasal,
reedy pulse. Sweeping the pulse width in real-time produces a
dynamic "phasing" effect which adds a sense of motion to
the sound. Rapidly jumping between different pulse widths can
produce interesting harmonic sequences.

NOISE (Bit 7) - When set to a one, the Noise output waveform of
Oscillator 1 is selected. This output is a random signal
which changes at the frequency of Oscillator 1. The sound
quality can be varied from a low rumbling to hissing white
noise via the Oscillator 1 Frequency registers. Noise is useful
in creating explosions, gunshots, jet engines, wind, surf and
other unpitched sounds, as well as snare drums and cymbals.
Sweeping the oscillator frequency with Noise selected produces
a dramatic rushing effect.

One of the output waveforms must be selected for Oscillator 1 to
be audible, however, it is NOT necessary to deselect waveforms to
silence the output of Voice 1. The amplitude of Voice 1 at the final
output is a function of the Envelope Generator only.

NOTE: The oscillator output waveforms are NOT additive. If more
than one output waveform is selected simultaneously, the result will be a
logical ANDing of the waveforms. Although this technique can be used to
generate additional waveforms beyond the four listed above, it must be
used with care. If any other waveform is selected while Noise is
on, the Noise output can "lock up". If this occurs, the Noise output
will remain silent until reset by the TEST bit or by bringing RES (pin 5)
low.

ATTACK/DECAY (Register 05) -

Bits 4-7 of this register (ATK0-ATK3) select 1 of 16 ATTACK rates for the Voice 1 Envelope Generator. The ATTACK rate determines how rapidly the output of Voice 1 rises from zero to peak amplitude when the Envelope Generator is Gated. The 16 ATTACK rates are listed below in Table 2.

Bits 0-3 (DCY0-DCY3) select 1 of 16 DECAY rates for the Envelope Generator. The DECAY cycle follows the ATTACK cycle and the DECAY rate determines how rapidly the output falls from the peak amplitude to the selected SUSTAIN level. The 16 DECAY rates are listed in Table 2.

SUSTAIN/RELEASE (Register 06) -

Bits 4-7 of this register (STN0-STN3) select 1 of 16 SUSTAIN levels for the Envelope Generator. The SUSTAIN cycle follows the DECAY cycle and the output of Voice 1 will remain at the selected SUSTAIN amplitude as long as the Gate bit remains set. The SUSTAIN levels range from zero to peak amplitude in 16 linear steps, with a SUSTAIN value of 0 selecting zero amplitude and a SUSTAIN value of 15 ($F) selecting the peak amplitude. A SUSTAIN value of 8 would cause Voice 1 to SUSTAIN at an amplitude one-half the peak amplitude reached by the ATTACK cycle.

Bits 0-3 (RLS0-RLS3) select 1 of 16 RELEASE rates for the Envelope Generator. The RELEASE cycle follows the SUSTAIN cycle when the Gate bit is reset to zero. At this time, the output of Voice 1 will fall from the SUSTAIN amplitude to zero amplitude at the selected RELEASE rate. The 16 RELEASE rates are identical to the DECAY rates.

NOTE: The cycling of the Envelope Generator can be altered at any point via the Gate bit. The Envelope Generator can be Gated and Released without restriction. For example, if the Gate bit is reset before the envelope has finished the ATTACK cycle, the RELEASE cycle will immediately begin, starting from whatever amplitude had been reached. If the envelope is then Gated again (before the RELEASE cycle has reached zero amplitude), another ATTACK cycle will begin, starting from whatever amplitude had been reached. This technique can be used to generate complex amplitude envelopes via real-time software control.

TABLE 2 - ENVELOPE RATES

VALUE		ATTACK RATE	DECAY/RELEASE RATE
DEC	(HEX)	(Time/Cycle)	(Time/Cycle)
0	(0)	2 mS	6 mS
1	(1)	8 mS	24 mS
2	(2)	16 mS	48 mS
3	(3)	24 mS	72 mS
4	(4)	38 mS	114 mS
5	(5)	56 mS	168 mS
6	(6)	68 mS	204 mS
7	(7)	80 mS	240 mS
8	(8)	100 mS	300 mS
9	(9)	250 mS	750 mS
10	(A)	500 mS	1.5 S
11	(B)	800 mS	2.4 S
12	(C)	1 S	3 S
13	(D)	3 S	9 S
14	(E)	5 S	15 S
15	(F)	8 S	24 S

NOTE: Envelope rates are based on a 1.0 Mhz 02 clock. For other 02 frequencies, multiply the given rate by 1 Mhz/02. The rates refer to the amount of time per cycle. For example, given an ATTACK value of 2, the ATTACK cycle would take 16 mS to rise from zero to peak amplitude. The DECAY/RELEASE rates refer to the amount of time these cycles would take to fall from peak amplitude to zero.

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VOICE 2

Registers 07-#0D control Voice 2 and are functionally identical to registers 00-06 with these exceptions:

When selected, SYNC synchronizes Oscillator 2 with Oscillator 1.
When selected, RING MOD replaces the Triangle output of Oscillator 2 with the ring modulated combination of Oscillators 2 and 1.

VOICE 3

Registers $0E-$14 control Voice 3 and are functionally identical to registers 00-06 with these exceptions:

When selected, SYNC synchronizes Oscillator 3 with Oscillator 2.
When selected, RING MOD replaces the Triangle output of Oscillator 3 with the ring modulated combination of Oscillators 3 and 2.

Typical operation of a voice consists of selecting the desired parameters: frequency, waveform, effects (SYNC, RING MOD) and envelope rates, then gating the voice whenever the sound is desired. The sound can be sustained for any length of time and terminated by clearing the Gate bit. Each voice can be used separately, with independent parameters and gating, or in unison to create a single, powerful voice. When used in unison, a slight detuning of each oscillator or tuning to musical intervals creates a rich, animated sound.

FILTER

FC LO/FC HI (Registers $15,$16) –
Together these registers form an 11-bit number (bits 3-7 of FC LO are not used) which linearly controls the Cutoff (or Center) Frequency of the programmable Filter. The approximate Cutoff Frequency is determined by the following equation:

$$FCout = ((6.6E-8 + FCn * 1.29E-8)/C) \ Hz$$

Where FCn is the 11-bit number in the Cutoff registers and C is the value of the two Filter capacitors connected to pins 1-4. For the recommended capacitor value of 2200 pF, the approximate range of the Filter is 30 Hz-12 kHz according to the following equation:

$$FCout = (30 + FCn * 5.8) \ Hz$$

The frequency range of the Filter can be altered to suit specific applications. Refer to the Pin Description section for more information.

RES/FILT (Register $17) –
Bits 4-7 of this register (RES0-RES3) control the Resonance of the Filter. resonance is a peaking effect which emphasizes frequency components at the Cutoff Frequency of the Filter, causing a sharper sound. There are 16 Resonance settings ranging linearly from no resonance (0) to maximum resonance (15 or $F).
Bits 0-3 determine which signals will be routed through the Filter:

FILT 1 (Bit 0) – When set to a zero, Voice 1 appears directly at the audio output and the Filter has no effect on it. When set to a one, Voice 1 will be processed through the Filter and the harmonic content of Voice 1 will be altered according to the selected Filter parameters.

FILT 2 (Bit 1) – Same as bit 0 for Voice 2.

FILT 3 (Bit 2) - Same as bit 0 for Voice 3.

FILTEX (Bit 3) - Same as bit 0 for External audio input (pin 26).

MODE/VOL (Register $18) -

Bits 4-7 of this register select various Filter mode and output options:

LP (Bit 4) - When set to a one, the Low Pass output of the Filter
is selected and sent to the audio output. For a given Filter
input signal, all frequency components below the Filter Cutoff
Frequency are passed unaltered, while all frequency components
above the Cutoff are attenuated at a rate of 12 dB/Octave. The
Low Pass mode produces full-bodied sounds.

BP (Bit 5) - Same as bit 4 for the Band Pass output. All frequency
components above and below the Cutoff are attenuated at a
rate of 6 dB/Octave. The Band Pass mode produces thin, open
sounds.

HP (Bit 6) - Same as bit 4 for the High Pass output. All frequency
components above the Cutoff are passed unaltered, while all
frequency components below the Cutoff are attenuated at a rate
of 12 dB/Octave. The High Pass mode produces tinny, buzzy
sounds.

3 OFF (Bit 7) - When set to a one, the output of Voice 3 is
disconnected from the direct audio path. Setting Voice 3
to bypass the Filter (FILT 3=0) and setting 3 OFF to
a one prevents Voice 3 from reaching the audio output. This
allows Voice 3 to be used for modulation purposes without any
undesirable output. More information on modulation effects
can be found in Appendix C.

NOTE: The Filter output modes ARE additive and multiple Filter modes
may be selected simultaneously. For example, both LP and HP modes can
be selected to produce a Notch (or Band Reject) Filter response. In
order for the Filter to have any audible effect, at least one Filter
output must be selected and and at least one Voice must be routed through
the Filter. The Filter is, perhaps, the most important element in SID
as it allows the generation of complex tone colors via subtractive
synthesis (the Filter is used to eliminate specific frequency components
from a harmonically-rich input signal). The best results are achieved
by varying the Cutoff Frequency in real-time. Further discussion of the
Filter appears in Appendix C.

Bits 0-3 (VOL0-VOL3) select 1 of 16 overall Volume levels for the final
composite audio output. The output volume levels range from no output (0) to
maximum volume (15 or $F) in 16 linear steps. This control can be used as
a static volume control for balancing levels in multi-chip systems or for
creating dynamic volume effects, such as Tremolo. Some Volume level other
than zero must be selected in order for SID to produce any sound.

MISC

POTX (Register $19) -

This register allows the microprocessor to read the position of the potentiometer tied to POTX (pin 24), with values ranging from 0 at minimum resistance, to 255 ($FF) at maximum resistance. The value is always valid and is updated every 512 02 clock cycles. See the Pin Description section for information on pot and capacitor values.

POTY (Register $1A) -

Same as POTX for the pot tied to POTY (pin 23).

OSC 3/RANDOM (Register $1B) -

This register allows the microprocessor to read the upper 8 output bits of Oscillator 3. The character of the numbers generated is directly related to the waveform selected. If the Sawtooth waveform of Oscillator 3 is selected, this register will present a series of numbers incrementing from 0 to 255 ($FF) at a rate determined by the frequency of Oscillator 3. If the Triangle waveform is selected, the output will increment from 0 up to 255, then decrement down to 0. If the Pulse waveform is selected, the output will jump between 0 and 255. Selecting the Noise waveform will produce a series of random numbers, therefore, this register can be used as a random number generator for games. There are numerous timing and sequencing applications for the OSC 3 register, however, the chief function is probably that of a modulation generator.
The numbers generated by this register can be added, via software, to the Oscillator or Filter Frequency registers or the Pulse Width registers in real-time. Many dynamic effects can be generated in this manner. Siren-like sounds can be created by adding the OSC 3 Sawtooth output to the frequency control of another oscillator. Synthesizer "Sample and Hold" effects can be produced by adding the OSC 3 Noise output to the Filter Frequency control registers. Vibrato can be produced by setting Oscillator 3 to a frequency around 7 Hz and adding the OSC 3 Triangle output (with proper scaling) to the Frequency control of another oscillator. An unlimited range of effects are available by altering the frequency of Oscillator 3 and scaling the OSC 3 output. Normally, when Oscillator 3 is used for modulation, the audio output of Voice 3 should be eliminated (3 OFF=1).

ENV 3 (Register $1C) -

Same as OSC 3, but this register allows the microprocessor to read the output of the Voice 3 Envelope Generator. This output can be added to the Filter Frequency to produce harmonic envelopes, WAH WAH, and similar effects. "Phaser" sounds can be created by adding this output to the frequency control registers of an oscillator. The Voice 3 Envelope Generator must be Gated in order to produce any output from this register. The OSC 3 register, however, always reflects the changing output of the oscillator and is not affected in any way by the Envelope Generator. Further information on modulation can be found in Appendix C.

SID PIN DESCRIPTION

CAP1A,CAP1B (Pins 1,2)/ CAP2A,CAP2B (Pins 3,4) - These pins are used to connect the two integrating capacitors required by the programmable Filter. C1 connects between pins 1 and 2, C2 between pins 3 and 4. Both capacitors should be the same value. Normal operation of the Filter over the audio range (approximately 30 Hz-12 kHz) is accomplished with a value of 2200 pF for C1 and C2. Polystyrene capacitors are preferred and in complex polyphonic systems, where many SID chips must track each other, matched capacitors are recommended. The frequency range of the Filter can be tailored to specific applications by the choice of capacitor values. For example, a low-cost game may not require full high-frequency response. In this case, larger values for C1 and C2 could be chosen to provide more control over the bass frequencies of the Filter. The maximum Cutoff Frequency of the Filter is given by:

$$FCmax = 2.6E-5/C$$

Where C is the capacitor value. The range of the Filter extends 9 octaves below the maximum Cutoff Frequency.

$\overline{RES}$ (Pin 5) - This TTL-level input is the reset control for SID. When brought low for at least ten Ø2 cycles, all internal registers are reset to zero and the audio output is silenced. This pin is normally connected to the reset line of the microprocessor or a power-on-clear circuit.

Ø2 (Pin 6) - This TTL-level input is the master clock for SID. All oscillator frequencies and envelope rates are referenced to this clock. Ø2 also controls data transfers between SID and the microprocessor. Data can only be transferred when Ø2 is high. Essentially, Ø2 acts as a high-active chip select as far as data transfers are concerned. This pin is normally connected to the system clock, with a nominal operating frequency of 1.0 MHz.

R/$\overline{W}$ (Pin 7) - This TTL-level input controls the direction of data transfers between SID and the microprocessor. If the chip select conditions have been met, a high on this line allows the microprocessor to Read data from the selected SID register and a low allows the microprocessor to Write data into the selected SID register. This pin is normally connected to the system Read/Write line.

$\overline{CS}$ (Pin 8) - This TTL-level input is a low active chip select which controls data transfers between SID and the microprocessor. $\overline{CS}$ must be low for any transfer. A Read from the selected SID register can only occur if $\overline{CS}$ is low, Ø2 is high and R/$\overline{W}$ is high. A Write to the selected SID register can only occur if $\overline{CS}$ is low, Ø2 is high and R/$\overline{W}$ is low. This pin is normally connected to address decoding circuitry, allowing SID to reside in the memory map of a system.

A0-A4 (Pins 9-13) - These TTL-level inputs are used to select one of the 29 SID registers. Although enough addresses are provided to select 1 of 32 registers, the remaining three register locations are not used. A Write to any of these three locations is ignored and a Read returns invalid data. These pins are normally connected to the corresponding address lines of the microprocessor so that SID may be addressed in the same manner as memory.

GND (Pin 14) - For best results, the ground line between SID and the power supply should be separate from ground lines to other digital circuitry. This will minimize digital noise at the audio output.

D0-D7 (Pins 15-22) - These bidirectional lines are used to transfer data
between SID and the microprocessor. They are TTL compatible in the
input mode and capable of driving 2 TTL loads in the output mode. The
data buffers are usually in the high-impedance off state. During
write operation, the data buffers remain in the off (input) state and the
microprocessor supplies data to SID over these lines. During a Read
operation, the data buffers turn on and SID supplies data to the micro-
processor over these lines. The pins are normally connected to the
corresponding data lines of the microprocessor.

POTX,POTY (Pins 24,23) - These pins are inputs to the A/D converters used
to digitize the position of potentiometers. The conversion process is
based on the time constant of a capacitor tied from the POT pin to
ground, charged by a potentiometer tied from the POT pin to +5 volts.
The component values are determined by:

$$RC = 4.7E-4$$

Where R is the maximum resistance of the pot and C is the capacitor.
The larger the capacitor, the smaller the POT value jitter.
The recommended values for R and C are 470 KOhms and 1000 pF.
Note that a separate pot and cap are required for each POT pin.

Vcc (Pin 25) - As with the GND line, a separate +5 VDC line should be run
between SID Vcc and the power supply in order to minimize noise. A bypass
capacitor should be located close to the pin.

EXT IN (Pin 26) - This analog input allows external audio signals to be mixed
with the audio output of SID or processed through the Filter. Typical
sources include voice, guitar and organ. The input impedance of this pin is
on the order of 100 KOhms. Any signal applied directly to the pin should ride
at a DC level of 6 volts and should not exceed 3 volts p-p. In order to
prevent any interference caused by DC level differences, external signals
should be AC-coupled to EXT IN by an electrolytic capacitor in the 1-10 uF
range. As the direct audio path (FILTEX=0) has unity gain, EXT IN can be
used to mix outputs of many SID chips by daisy-chaining. The number of chips
that can be chained in this manner is determined by the amount of noise and
distortion allowable at the final output. Note that the output Volume
control will affect not only the three SID voices, but also any external
inputs.

AUDIO OUT (Pin 27) - This open-source buffer is the final audio output
of SID, comprised of the three SID voices, the Filter and any
external input. The output level is set by the output Volume control and
reaches a maximum of 2 volts p-p at a DC level of 6 volts. A source
resistor from AUDIO OUT to ground is required for proper operation.
The recommended resistance is 1 kOhm for a standard output impedance. As
the output of SID rides at a 6 volt DC level, it should be AC-coupled to
any audio amplifier with an electrolytic capacitor in the 1-10 uF range.

Vdd (Pin 28) - As with Vcc, a separate +12 VDC line should be
run to SID Vdd and a bypass capacitor should be used.

ABSOLUTE MAXIMUM RATINGS

RATING	SYMBOL	VALUE	UNITS
Supply Voltage	Vdd	-0.3 to +17	VDC
Supply Voltage	Vcc	-0.3 to +7	VDC
Input Voltage (analog)	Vina	-0.3 to +17	VDC
Input Voltage (digital)	Vind	-0.3 to +7	VDC
Operating Temperature	Ta	0 to +70	°C
Storage Temperature	Tstg	-55 to +150	°C

ELECTRICAL CHARACTERISTICS (Vdd=12 ± 5% VDC, Vcc=5 ± 5% VDC, Ta=0 to 70°C)						
CHARACTERISTIC		SYMBOL	MIN	TYP	MAX	UNITS
Input High Voltage	(RES, 02, R/W, CS,	Vih	2	-	Vcc	VDC
Input Low Voltage	A0-A4, D0-D7)	Vil	-0.3	-	0.8	VDC
Input Leakage Current	(RES, 02, R/W, CS, A0-A4; Vin=0-5 VDC)	Iin	-	-	2.5	uA
Three-State (Off) Input Leakage Current	(D0-D7; Vcc=max, Vin=0.4-2.4 VDC)	Itsi	-	-	10	uA
Output High Voltage	(D0-D7; Vcc=min, I load=200 uA)	Voh	2.4	-	Vcc-0.7	VDC
Output Low Voltage	(D0-D7; Vcc=max, I load=3.2 mA)	Vol	GND	-	0.4	VDC
Output High Current	(D0-D7; Sourcing, Voh=2.4 VDC)	Ioh	200	-	-	uA
Output Low Current	(D0-D7; Sinking, Vol=0.4 VDC)	Iol	3.2	-	-	mA
Input Capacitance	(RES, 02, R/W, CS, A0-A4, D0-D7)	Cin	-	-	10	pF
Pot Trigger Voltage	(POTX, POTY)	Vpot	-	Vcc/2	-	VDC
Pot Sink Current	(POTX, POTY)	Ipot	500	-	-	uA
Input Impedance	(EXT IN)	Rin	100	150	-	KOhms
Audio Input Voltage	(EXT IN)	Vin	5.7 -	6 0.5	6.3 3	VDC VAC
Audio Output Voltage	(AUDIO OUT; 1 KOhm load, volume=max) One Voice on: All Voices on:	Vout	5.7 0.4 1.0	6 0.5 1.5	6.3 0.6 2.0	VDC VAC VAC
Power Supply Current	(Vdd)	Idd	-	20	25	mA
Power Supply Current	(Vcc)	Icc	-	70	100	mA
Power Dissipation	(Total)	Pd	-	600	1000	mW

COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only. Functional operation of this device at these or any other conditions above those indicated in the operational sections of this specification is not implied and exposure to absolute maximum rating conditions for extended periods may affect device reliability.

All inputs contain protection circuitry to prevent damage due to high static discharges. Care should be exercised to prevent unnecessary application of voltages in excess of the allowable limits.

READ CYCLE

*Tacc IS MEASURED FROM THE LATEST OCCURING OF ϕ_2, $\overline{CS}$, A0-A4
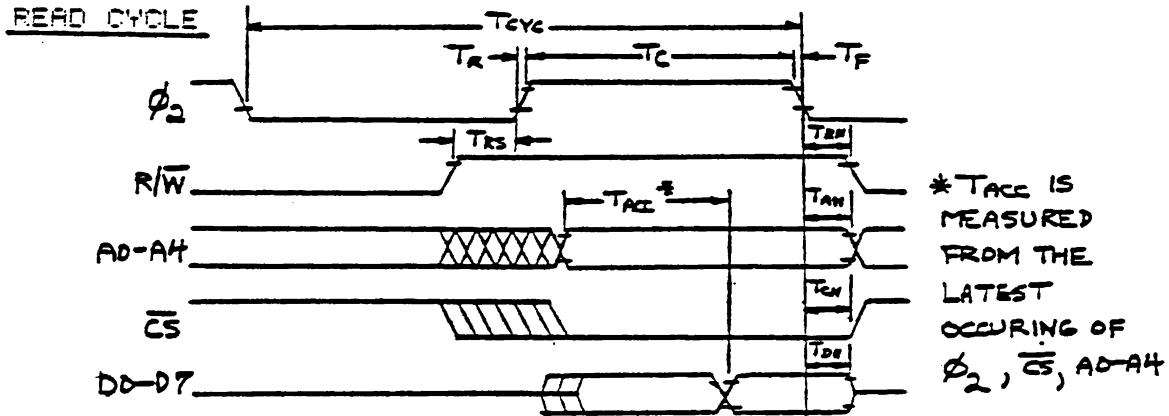
SYMBOL	NAME	MIN	TYP	MAX	UNITS
Tcyc	Clock Cycle Time	1	–	20	uS
Tc	Clock High Pulse Width	450	500	10,000	nS
Tr,Tf	Clock Rise/Fall Time	–	–	25	nS
Trs	Read Set-up Time	0	–	–	nS
Trh	Read Hold Time	0	–	–	nS
Tacc	Access Time	–	–	300	nS
Tah	Address Hold Time	10	–	–	nS
Tch	Chip Select Hold Time	0	–	–	nS
Tdh	Data Hold Time	20	–	–	nS

WRITE CYCLE

*Tw IS MEASURED FROM THE LATEST OCCURING OF ϕ_2, $\overline{CS}$, R/$\overline{W}$
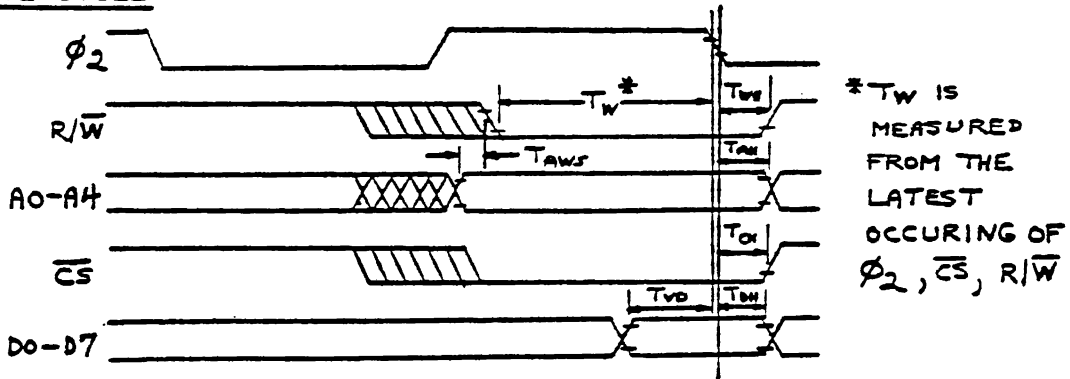
| SYMBOL	NAME	MIN	TYP	MAX	UNITS
Tw	Write Pulse Width	350	–	–	nS
Twh	Write Hold Time	0	–	–	nS
Taws	Address Set-up Time	0	–	–	nS
Tah	Address Hold Time	10	–	–	nS
Tch	Chip Select Hold Time	0	–	–	nS
Tvd	Valid Data	80	–	–	nS
Tdh	Data Hold Time	10	–	–	nS

APPENDIX A - EQUAL-TEMPERED MUSICAL SCALE VALUES

The following table lists the numerical values which must be stored in the SID Oscillator frequency control registers to produce the notes of the equal-tempered musical scale. The equal-tempered scale consists of an octave containing 12 semitones (notes): C,D,E,F,G,A,B and C#,D#,F#,G#,A#. The frequency of each semitone is exactly the 12th root of 2 ($\sqrt[12]{2}$) times the frequency of the previous semitone. The table is based on a Ø2 clock of 1.0 Mhz. Refer to the equation given in the Register Description for use of other master clock frequencies. The scale selected is concert pitch, in which A4 = 440 Hz. Transpositions of this scale and scales other than the equal-tempered scale are also possible.

MUSICAL NOTE		FREQ (Hz)	OSC Fn (DECIMAL)	OSC Fn (HEX)	MUSICAL NOTE		FREQ (Hz)	OSC Fn (DECIMAL)	OSC Fn (HEX)
0	C0	16.35	274	0112	48	C4	261.63	4389	1125
1	C0#	17.32	291	0123	49	C4#	277.18	4650	122A
2	D0	18.35	308	0134	50	D4	293.66	4927	133F
3	D0#	19.44	326	0146	51	D4#	311.13	5220	1464
4	E0	20.60	346	015A	52	E4	329.63	5530	159A
5	F0	21.83	366	016E	53	F4	349.23	5859	16E3
6	F0#	23.12	388	0184	54	F4#	370.00	6207	183F
7	G0	24.50	411	019B	55	G4	392.00	6577	19B1
8	G0#	25.96	435	01B3	56	G4#	415.30	6968	1B38
9	A0	27.50	461	01CD	57	A4	440.00	7382	1CD6
10	A0#	29.14	489	01E9	58	A4#	466.16	7821	1E8D
11	B0	30.87	518	0206	59	B4	493.88	8296	205E
12	C1	32.70	549	0225	60	C5	523.25	8779	224B
13	C1#	34.65	581	0245	61	C5#	554.37	9301	2455
14	D1	36.71	616	0268	62	D5	587.33	9854	267E
15	D1#	38.89	652	028C	63	D5#	622.25	10440	28C8
16	E1	41.20	691	02B3	64	E5	659.26	11060	2B34
17	F1	43.65	732	02DC	65	F5	698.46	11718	2DC6
18	F1#	46.25	776	0308	66	F5#	740.00	12415	307F
19	G1	49.00	822	0336	67	G5	783.99	13153	3361
20	G1#	51.91	871	0367	68	G5#	830.61	13935	366F
21	A1	55.00	923	039B	69	A5	880.00	14764	39AC
22	A1#	58.27	978	03D2	70	A5#	932.33	15642	3D1A
23	B1	61.74	1036	040C	71	B5	987.77	16572	40BC
24	C2	65.41	1097	0449	72	C6	1046.50	17557	4495
25	C2#	69.30	1163	048B	73	C6#	1108.73	18601	48A9
26	D2	73.42	1232	04D0	74	D6	1174.66	19708	4CFC
27	D2#	77.78	1305	0519	75	D6#	1244.51	20897	518F
28	E2	82.41	1383	0567	76	E6	1318.51	22121	5669
29	F2	87.31	1465	05B9	77	F6	1396.91	23436	5B8C
30	F2#	92.50	1552	0610	78	F6#	1479.98	24830	60FE
31	G2	98.00	1644	066C	79	G6	1567.98	26306	66C2
32	G2#	103.83	1742	06CE	80	G6#	1661.22	27871	6CDF
33	A2	110.00	1845	0735	81	A6	1760.00	29528	7358
34	A2#	116.54	1955	07A3	82	A6#	1864.65	31284	7A34
35	B2	123.47	2071	0817	83	B6	1975.53	33144	8178
36	C3	130.81	2195	0893	84	C7	2093.00	35115	892B
37	C3#	138.59	2325	0915	85	C7#	2217.46	37203	9153
38	D3	146.83	2463	099F	86	D7	2349.32	39415	99F7
39	D3#	155.56	2610	0A32	87	D7#	2489.01	41759	A31F
40	E3	164.81	2765	0ACD	88	E7	2637.02	44242	ACD2
41	F3	174.61	2930	0B72	89	F7	2793.83	46873	B719
42	F3#	185.00	3104	0C20	90	F7#	2959.95	48660	C1FC
43	G3	196.00	3288	0CD8	91	G7	3135.96	52613	CD85
44	G3#	207.65	3484	0D9C	92	G7#	3322.44	55741	D9BD
45	A3	220.00	3691	0E6B	93	A7	3520.00	59056	E6B0
46	A3#	233.08	3910	0F46	94	A7#	3729.31	62567	F467
47	B3	246.94	4143	102F	95	B7	3951.06	*66288	*1F2F0

Although the table above provides a simple and quick method for generating the equal-tempered scale, it is very memory inefficient as it requires 192 bytes for the table alone. Memory efficiency can be improved by determining the note value algorithmically. Using the fact that each note in an octave is exactly half the frequency of that note in the next octave, the note look-up table can be reduced from 96 entries to 12 entries, as there are 12 notes per octave. If the 12 entries (24 bytes) consist of the 16-bit values for the eighth octave (C7 through B7), then notes in lower octaves can be derived by choosing the appropriate note in the eighth octave and dividing the 16-bit value by two for each octave of difference. As division by two is nothing more than a right-shift of the value, the calculation can easily be accomplished by a simple software routine. Although note B7 is beyond the range of the Oscillators, this value should still be included in the table for calculation purposes (the MSB of B7 would require a special software case, such as generating this bit in the CARRY before shifting). Each note must be specified in a form which indicates which of the 12 semitones is desired, and which of the eight octaves the semitone is in. Since four bits are necessary to select 1 of 12 semitones and three bits are necessary to select 1 of 8 octaves, the information can fit in one byte, with the lower nybble selecting the semitone (by addressing the look-up table) and the upper nybble being used by the division routine to determine how many times the table value must be right-shifted.

The four-part ADSR (ATTACK, DECAY, SUSTAIN, RELEASE) envelope generator has been proven in electronic music to provide the optimum trade-off beweteen flexibility and ease of amplitude control. Appropriate selection of envelope parameters allows the simulation of a wide range of percussion and sustained instruments. The violin is a good example of a sustained instrument. The violinist controls the volume by bowing the instrument. Typically, the volume builds slowly, reaches a peak, then drops to an intermediate level. The violinist can maintain this level for as long as desired, then the volume is allowed to slowly die away. A "snapshot" of this envelope is shown below:

PEAK AMPLITUDE

|←A→|D|←SUSTAIN PERIOD→|←R→|

INTERMEDIATE LEVEL

ZERO AMPLITUDE
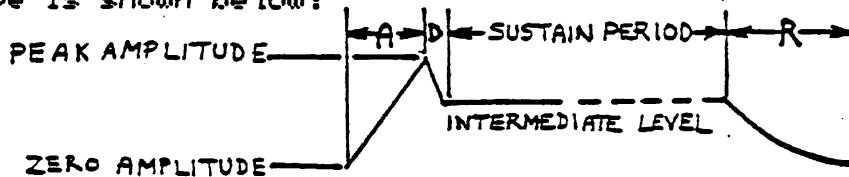
This volume envelope can be easily reproduced by the ADSR as shown below, with typical envelope rates:

```
ATTACK:   10 ($A)    500 mS
DECAY:     8         300 mS
SUSTAIN:  10 ($A)
RELEASE:   9         750 mS
```

A D S R / GATE
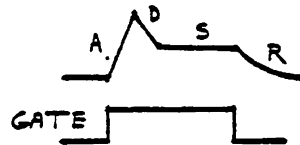
Note that the tone can be held at the intermediate SUSTAIN level for as long as desired. The tone will not begin to die away until GATE is cleared. With minor alterations, this basic envelope can be used for brass and woodwinds as well as strings.

An entirely different form of envelope is produced by percussion instruments such as drums, cymbals and gongs, as well as certain keyboards such as pianos and harpsichords. The percussion envelope is characterized by a nearly instantaneous attack, immediately followed by a decay to zero volume. Percussion instruments cannot be sustained at a constant amplitude. For example, the instant a drum is struck, the sound reaches full volume and decays rapidly regardless of how it was struck. A typical cymbal envelope is shown below:

```
ATTACK:   0     2 mS
DECAY:    9    750 mS
SUSTAIN:  0
RELEASE:  9    750 mS
```

A D GATE
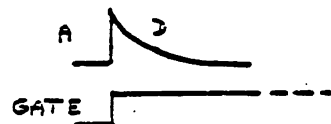
Note that the tone immediately begins to decay to zero amplitude after the peak is reached, regardless of when GATE is cleared. The amplitude envelope of pianos and harpsichords is somewhat more complicated, but can be generated quite easily with the ADSR. These instruments reach full volume when a key is first struck. The amplitude immediately begins to die away slowly as long as the key remains depressed. If the key is released before the sound has fully died away, the amplitude will immediately drop to zero. This envelope is shown below:

```
ATTACK:   0     2 mS
DECAY:    9    750 mS
SUSTAIN:  0
RELEASE:  0     6 mS
```

A D R GATE
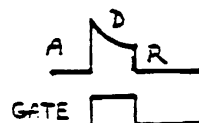
Note that the tone decays slowly until GATE is cleared, at which point the amplitude drops rapidly to zero.

16

The most simple envelope is that of the organ. When a key is pressed, the tone immediately reaches full volume and remains there. When the key is released, the tone drops immediately to zero volume. This envelope is shown below:

```
ATTACK:     0      2 mS
DECAY:      0      6 mS
SUSTAIN: 15 ($F)
RELEASE:    0      6 mS
```
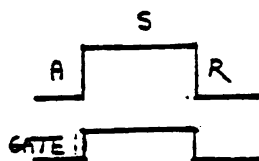
The real power of SID lies in the ability to create original sounds rather than simulations of acoustic instruments. The ADSR is capable of creating envelopes which do not correspond to any "real" instruments. A good example would be the "backwards" envelope. This envelope is characterized by a slow attack and rapid decay which sounds very much like an instrument that has been recorded on tape then played backwards. This envelope is shown below:

```
ATTACK:    10 ($A)  500 mS
DECAY:      0          6 mS
SUSTAIN: 15 ($F)
RELEASE:    3         72 mS
```
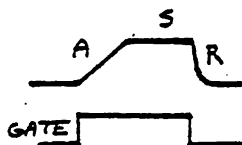
Many unique sounds can be created by applying the amplitude envelope of one instrument to the harmonic structure of another. This produces sounds similar to familiar acoustic instruments, yet notably different. In general, sound is quite subjective and experimentation with various envelope rates and harmonic contents will be necessary in order to achieve the desired sound.
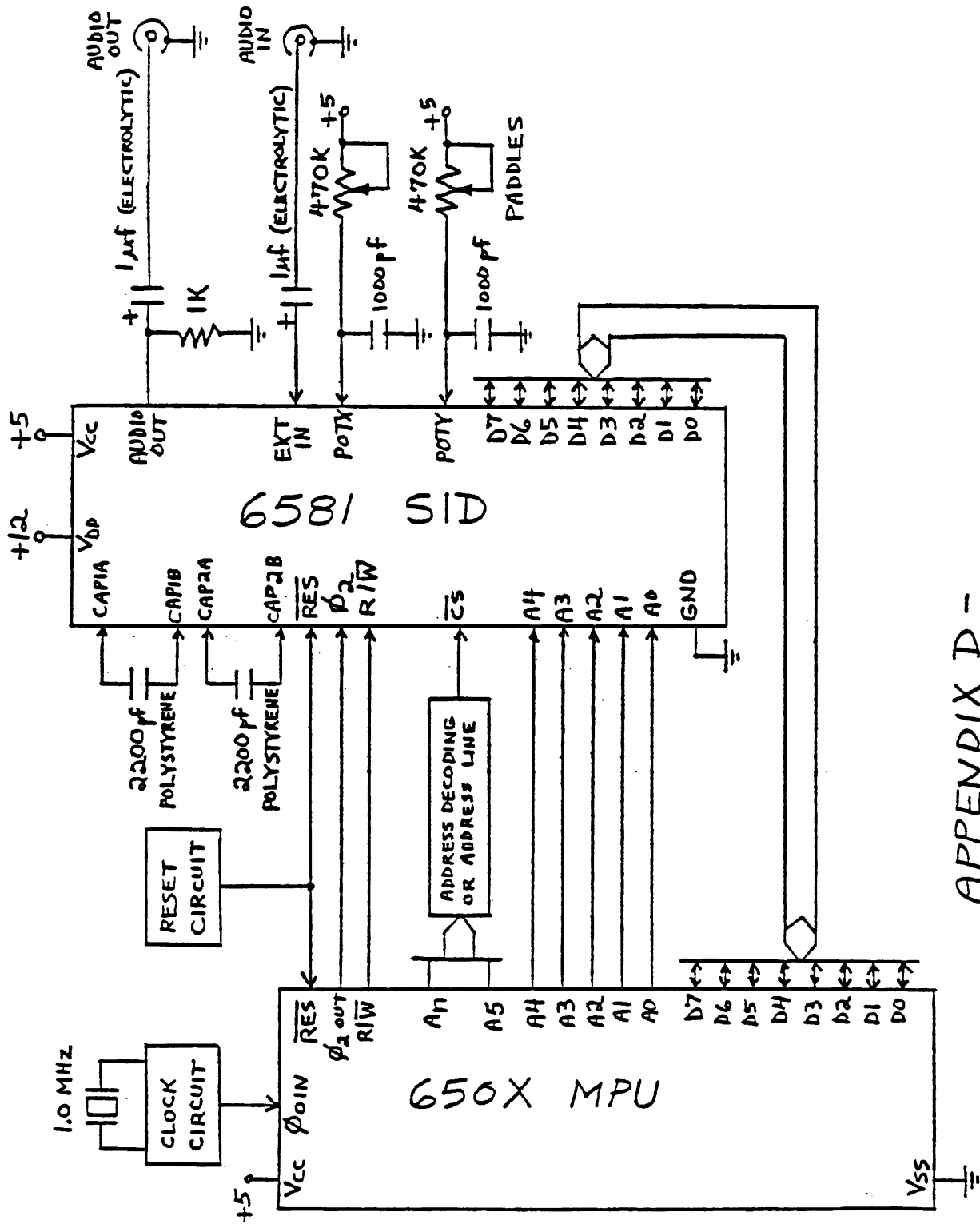
APPENDIX D —
TYPICAL 6581 SID APPLICATION

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